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(54) **Method for the linearization of the power stage of a signal transmitter, corresponding system and receiver**

(57) The system includes a transmitter (1) with a stage (9) susceptible to alter the signals transmitted, for instance distorting them. The effect of the alteration action made by the above mentioned stage (9) of the transmitter (1) is detected on the receiver side (2) generating a corresponding control signal (c_i) destined to be retransmitted to the transmitter (1), for instance using one of the service channels. Therefore, the transmitted signals can be subjected to pre-treatment, for instance through a pre-distorter (4) placed upstream the distorting stage (9). Preferential application to transmission of digital signals in systems in which the control signal (C_i) is generated with a feedback action based on the use of decision symbols ($a_R(n)$) obtained at the demodulator output.

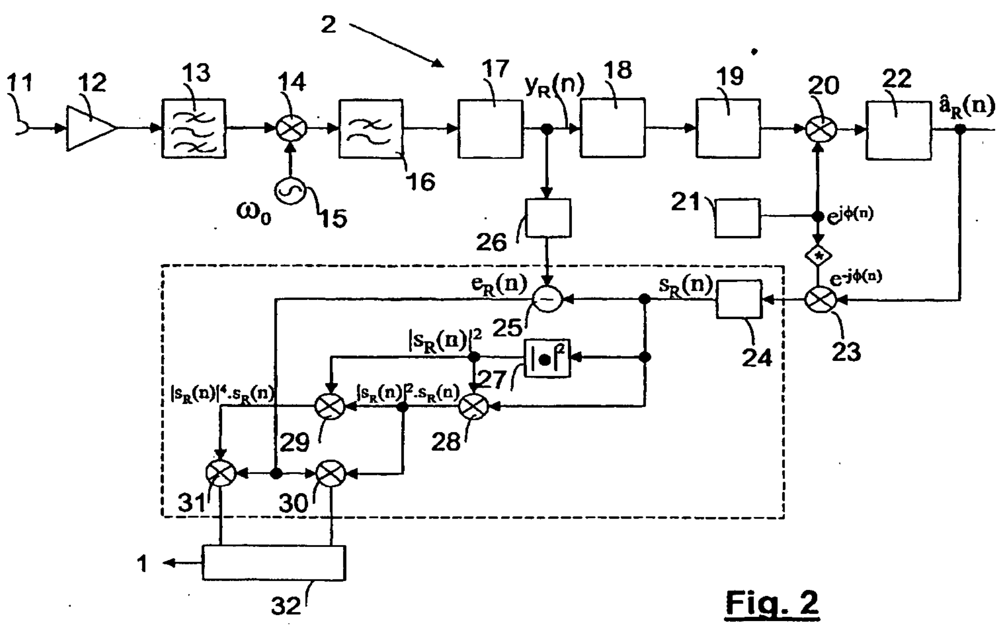

Fig. 2

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Description

Field of the invention

[0001] The present invention relates to signal transmission techniques, in particular in the context defined by the preamble of claim 1.

[0002] The invention has been developed with particular attention to the possible use in transmission systems in which the transmitter stage susceptible to alter the transmitted signals consists of the final power stage (High Power Amplifier or HPA) of a microwave transmitter employed in a point to point (Point-To-Point or PTP) or point- to-multipoint (Point-to-MultiPoint or PMP) radio connection.

[0003] The signal alteration action made by such a stage can essentially be referable to a distortion. Negative effects of said distortion are particularly perceived when a linear modulation format is used for transmission, such as a M-QAM format, in the case of digital signals.

Background art

[0004] It is already known how to face this problem implementing, at the transmitter side, a pre-treatment of signals with counteracting function of the alteration action made by the power stage HPA. This can be made through non-linear circuits implemented at intermediate frequency (IF) or at radio frequency (RF) placed upstream the power stage and susceptible to perform a pre-distortion action according to a complementary characteristic in respect of the distortion characteristic of the power stage.

[0005] As an alternative to the use of fixed pre-distortion circuits (implementing an essentially empirical and static linearization process, which does not enable to follow possible phenomena of thermal drift and aging) in the course of the years, techniques foreseeing to employ pre-distorters of digital type circuits have been proposed, implemented at base band level in the modulator. These circuits are controlled in adaptive mode - according to a general feedback scheme - by a control signal obtained comparing the samples of the digital signal applied to the pre-distorter input with corresponding samples of the signal at the power stage output.

[0006] The relevant literature is extremely wide, as demonstrated, for instance, by the paper by G. Karam and H. Sari, "Oversampled signal predistortion for digital radio systems with arbitrary transmit pulse shaping", 3rd ECRR Proceedings, Paris, pp 255-261, December 1991.

[0007] The main disadvantage of this solution (disadvantage that considerably limited the practical application of the same) is represented by the fact that, to obtain the control signal adapted to pilot the pre-distorter action, it is necessary to convert the output signal of the distorting power stage into a signal that can be used to control the pre-distorter. Beyond strictly technological aspects (the output signal to convert is usually a high frequency signal, typically a microwave one, while the control signal of the pre-distorter typically consists of a signal in base band converted into digital form), the feedback chain necessary to produce the control signal is a circuit set to all effects, an additional set compared to the transmitter basic diagram and therefore susceptible to negatively affect the complexity, reliability and mainly the cost of the transmitter.

Scope and summary of the invention

[0008] Scope of the present invention is to offer a solution capable of overcoming the above-mentioned drawback.

[0009] According to the present invention, this purpose is reached thanks to a method having the additional characteristics specifically recalled in the appended claims. The invention relates also to the corresponding system and, particularly, the relevant receiver.

[0010] In summary, the solution according to the invention foresees that the pre-treatment implemented at transmitter level (for instance through a pre-distorter implemented at base band level in the modulator) is piloted in an adaptive manner by a control signal generated in the receiver (typically at demodulator side) and retransmitted towards the transmitter.

[0011] The main advantage offered by this solution is given by the fact that the control signal used to pilot the pre-treatment is generated starting from signals already available in the receiver, without requiring the provision of additional circuits. Also concerning the retransmission of the control signal towards the transmitter, one of the service channels usually foreseen in such a connection can also be employed. The above, also, with a very limited occupation of the available resources (for instance, in terms of service channel frames), considering that - once correctly initialised - the pre-distorter control process is a phenomenon having a rather slow time evolution.

[0012] In a particularly preferred embodiment of the invention, it is foreseen that the control signal essentially corresponds to distortion terms of the third and fifth order generated in digital form starting from the linear signal in base band in the demodulator. In general, in fact, the pre-distorter has the characteristics of a three-taps equalizer in which

the tap relevant to the linear term is constant and real, while the taps of the third and fifth order (generally having the characteristics of a complex coefficient, including a real and an imaginary part) are subjected to the control signal coming from the demodulator in order to obtain the correct complex weighing factor, reversing the characteristic distorting the transmitter stage, or minimizing the signal /mean square error ratio (S/MSE) at the receiver side.

[0013] In a preferred way, the structure of the pre-distorter is based on a Volterra series without memory truncated at the fifth order. It is also possible to use higher order terms; in general, these do not contribute in a significant way to improve the system operation characteristics.

[0014] However, it is well known (also due to the wide literature available on the subject) that recourse is possible to pre-distortion algorithms of a different type. Therefore, the importance of the present invention has not to be considered limited neither by the specific algorithm considered nor - and in more general terms - to the utilization in the specific application field considered: in fact, the solution according to the invention is generally applicable to all the techniques where the implementation of a signal pre-treatment counteracting the alteration action made on such signals by a transmitter stage is foreseen.

Brief description of figures

[0015] The invention shall be now better understood from the following description given as an example, but not limited to the same, together with the attached figures, in which:

- Figure **1** and **2** are block diagrams representing the structure of the transmitter and receiver, respectively, of a transmission system operating according to the invention, and
- Figure **3** is a diagram showing the operation characteristics that can be noticed in a system according to the invention.

Detailed description of a preferred embodiment of the invention.

[0016] In the block diagrams of figures 1 and 2, the references 1 and 2 indicate a transmitter and a receiver, respectively, included in a system for the transmission of digital signals. To settle the idea, it can be a connection on radio link of the PTP or PMP type employing a linear modulation format, such as for instance M-QAM.

[0017] The flow of data at input $a_T(n)$ feeds a transmission filter 3 that generates a corresponding transmission signal $s_T(n)$ in base band adapted to supply a pre-distorter 4.

[0018] The signal $x_T(n)$ obtained at the pre-distorter 4 output is sent to a digital-to-analogue converter 5 to be then transferred to a modulator in quadrature 7 operating at the frequency (pulsation) ω_0 generated by a local oscillator 8. The modulated signal so obtained is transferred to a power stage (HPA), denoted with 9, to be sent towards a transmitting antenna 10.

[0019] The scheme described must be considered well known, both concerning the general architectural organization, and for the specific characteristics of the single devices 3 to 5 and 7 to 10 here considered.

[0020] In particular, this is worth also for the control signal used to pilot the pre-distorter 4. For reasons that shall result clearer in the continuation of the description, this signal is actually identified with two coefficients C_1 and C_2. These coefficients, which in general have the character of complex variables, can be obtained according to any of the criteria known to this purpose: in this respect, reference can be made to the volume by S. Benedetto, E. Biglieri and V. Castellani, "Digital Transmission Theory", Englewood Cliffs, NJ; Prentice-Hall, 1987.

[0021] Preferably, the pre-distorter 4 is implemented with digital circuits in the base band section of the transmitter, immediately after the transmission filter (FIR TX) 3 and immediately before the digital-to-analogue conversion represented by block 5 of figure 1.

[0022] Since this is a non linear system without memory (like the power stage 9), the pre-distorter 4 can be described with an input/output relation of the following type:

$$x_T(n)= s_T(n)+C_1\ |s_T(n)|^2 s_T(n)+ C_2\ |s_T(n)|^4 s_T(n)$$

where $s_T(n)$ is the signal coming out from the FIR TX 3 at the pre-distorter 4 input and $X_T(n)$ is the signal coming out from the latter - destined to be fed to the converter 5 - stopped at the distortion term of the fifth order.

[0023] In the block diagram of the receiver 2, the reference 11 indicates the receiving antenna. The signal received is caused to pass through a reception amplifier 12 and a noise rejection filter 13 to be then (re)converted in base band. This occurs by mixing, made in a mixer 14, with a local oscillator signal at the frequency (pulsation) ω_0 coming from an oscillator 15 and subsequent filtering 16 in view of the conversion to digital made in an analogue-to-digital converter 17.

[0024] At the output of the latter, a signal received and converted in base band $y_R(n)$ is therefore available.
[0025] Proceeding in the normal reception chain of the receiver, the numeric reference 18 indicates a reception filter (FIR RX), whose output signal is transferred by a base band equalizer 19.
[0026] All the above shall then be multiplied in a complex rotator 20 with a carrier synchronization signal coming from a PLL 21 performing the frequency and the transmission carrier phase recovery.
[0027] The signal so obtained is transferred to a decision block 22 generating at its output the sequence of (estimated) symbols received.
[0028] What described corresponds to a well-known receiver structure, both concerning the architecture of the same, and for the implementation characteristics of the single blocks 12 to 22 considered.
[0029] It could be noticed that in figure 1 and 2 the phase and quadrature channels (I and Q) included both in the transmitter 1 and in the receiver 2 have not been separately represented for drawing compactness and representation convenience. In any case - as those skilled in the art will easily identify - the signal in transit, and in particular the signal in transit in the portion of transmission and reception base band is in general a complex signal, as complex are in general the coefficients of the different filters/equalizers considered (of course, in addition to the coefficients of pre-distorter 4).
[0030] The solution according to the invention grounds on the acknowledgment of the fact that, since there is no element with memory between the output of pre-distorter 4 and the power stage (HPA) 9, the output of the latter, denoted $y_T(n)$ is a narrow band signal.
[0031] Therefore, the following expression for the equivalent low pass applies to the latter:

$$y_T(n) = b_0 s_T(n) + b_1 |s_T(n)|^2 s_T(n) + b_2 |s_T(n)|^4 s_T(n) + \dots$$

[0032] Consequently, the equivalent low-pass of the signal received is given by:

$$y_R(n) = y_T(n) \copyright f(n) + \eta(n) = b_0 s_T(n) \copyright f(n) + b_1 |s_T(n)|^2 s_T(n) \copyright f(n) +$$
$$b_2 |s_T(n)|^4 s_T(n) \copyright f(n) + \dots + \eta(n)$$

where:

- b_i are (complex) constants of the development,
- $\eta(n)$ is a white and additive Gaussian noise, and
- f(n) is the impulse response of the channel including all the radio frequency and intermediate frequency filters of the transmission and reception chain (with the sole exception of shaping filters).

[0033] Of course, the symbol © indicates the convolution operation.
[0034] The first term of the expression of $y_R(n)$ represents the linear component; the second term is the distortion component of the third order, the third one is the filth order component, and so on.
[0035] The target to attain is of course that to minimize the total content of terms different from the first one, appropriately adjusting the coefficients C_i of pre-distorter 4.
[0036] In the solution according to the invention, the linear component of the expression of $y_R(n)$ is reconstructed at demodulator level in the shape of a signal $s_R(n)$ obtained starting from the decided symbols a(n) available at the output of the decision circuit 22 de-rotated in a complex rotator 23 of the phase $\phi(n)$ of carrier recovery (PLL) and filtered in a filter FIR AUX 24 whose coefficients are initialised at the same values of the homologue filter FIR TX 3 present in transmitter 1.
[0037] For the signal $s_R(n)$, which can be seen as a model of signals $y_R(n)$, reconstructed on the basis of "decided" symbols, the following expression applies:

$$s_R(n) = \Sigma_k g(k) a_R(n-k) e^{-j\phi(n-k)}$$

[0038] In a sum node denoted with 25 an error signal $e_R(n) = y_R(n) - s_R(n)$ is reconstructed for each symbol received.
[0039] It shall be remembered that the signal $y_R(n)$ is available at the output of the analogue-to-digital converter 17 properly delayed in 26 up to the time alignment with the reconstructed signal $s_R(n)$.
[0040] The reference 27 indicates a block in which the squared module of the signal $s_R(n)$ is calculated, while references 28 to 31 indicate corresponding multipliers whose connection diagram - that can be clearly obtained from the

drawing - is such to originate at the output of multipliers 30 and 31, respectively, correlation coefficients c_i that can be expressed according to the relation

$$c_i = \langle \varepsilon(n) \left|s_R(n)\right|^{2i} s_R{}^*(n) \rangle \qquad \text{for } i = 1, 2$$

[0041] The correlation coefficients c_i essentially form the control signal, which when retransmitted towards the transmitter 1, can be used to generate the coefficients of pre-distorter 4, this performing the relevant adaptive control.

[0042] The transmission occurs through a chain of transmission elements denoted as a whole with 32 and made of elements of the known type: these are in fact the same elements generally available in a system 1, 2 of the type described for the transmission of service signals.

[0043] The calculation of the correlations defining coefficients c_i (we remember that - at least in principle - it is also possible to calculate coefficients of higher order, which however do not generally contribute in a significant way to additionally improve the system performances) is made at each new frame in view if retransmission towards the transmitter 1.

[0044] Here the coefficients of pre-distorter 4 are reconstructed accumulating the values of the relevant correlations according to a recursive expression of the type:

$$C_i(N_T+1) = C_i(N_T)-\beta c_i \qquad \text{per } i = 1, 2$$

where N_T is the frame time and β an appropriate step size factor.

[0045] The correct operation of the system foresees also the adjustment of coefficients g_k of the filter 24. In general, this occurs according an expression of the following type

$$g_k(n+1) = g_k(n)+\gamma\varepsilon(n)a_R{}^*(n-k)e^{j\phi(n-k)}$$

where γ is an appropriate step size factor.

[0046] This last operation is important in order that, at the end of the linearization process, $s_R(n)$ is as close as possible to $s_T(n)©f(n)$, therefore validating the capacity of the demodulator to reconstruct at its best the linear component of the received signal $y_R(n)$.

[0047] The experiences made by the Applicant, referring, as power stage 9, to a progressive wave amplifier (whose non-linear characteristic results more severe than that of solid state amplifiers) enabled to check the effectiveness of the proposed solution.

[0048] In particular, reference has been made to the criterion proposed in the paper of Karam and Sari, already mentioned above, which consists in the evaluation of the degrading of the signal/noise ratio obtained at a pre-set BER value (for instance 0.001).

[0049] It has been noticed that the solution according to the invention, implemented having recourse to a two tap pre-distorter 4, enables to obtain - compared to a system without pre-distortion function - a gain in the range of approximately 6 dB in terms of total degradation with a gain in terms of output back-off (defined as the difference in dB between the average power transmitted and the maximum saturation power at the HPA output) in the range of 5 dB approx.

[0050] The diagram in figure 3 shows the effect of the linearization technique implemented according to the invention on the spectrum of the signal coming out from the HPA for an output back-off (OBO) of 6 dB.

[0051] In particular, the diagram of figure 3 refers to the 128 QAM modulation format with roll-off equal to 0,18.

Therefore, while an embodiment of the present invention has been shown and described, it should be understood that other embodiments and/or additions can be made by those skilled in the art without departing from the scope thereof.

Claims

1. Method to transmit signals towards a receiver (2) starting from a transmitter (1) including a stage (9) adapted to alter the signals transmitted, the method including the following steps:

   - detecting (23 to 32) the effect of the alteration action made by said stage (9) of the transmitter (1) on the transmitted signals, generating a corresponding control signal (c_i) indicative of the effect of said alteration action, and

- subjecting said signals, operating upstream said stage (9) according to said control signal (c_i), to a pre-treatment (4) counteracting the alteration action made by said stage (9) of the transmitter (1),

characterized in that it includes the following steps:

- performing said detection action (23 to 32), generating said control signal (c_i) starting from said signals as they are received in the receiver (2), and
- transmitting (32) the control signal (c_i) so generated by the receiver (2) towards the transmitter (1).

2. Method according to claim 1, **characterized in that** said pre-treatment is a pre-distortion treatment (4) of said signals.

3. Method according to claim 1 or claim 2, applied to a transmitter in which said stage (9) is a radio frequency stage distorting transmitted signals.

4. Method according to any of the previous claims, applied to the transmission of digital signals and **characterized in that** it includes the following steps:

- performing in said receiver (2) a decision operation (22) on said digital signals in order to generate decision signals ($a_R(n)$) corresponding to digital signals transmitted,
- reconstructing (23, 24) starting from said decision signals ($a_R(n)$) a reference model ($s_R(n)$) of said signals transmitted ($y_R(n)$),
- generating (25) an error signal ($\varepsilon_R(n)$) indicative of the difference between said signals received ($y_R(n)$) and said reference model ($s_R(n)$), and
- generating said control signal (c_i) through correlation of said reference signals ($s_R(n)$) and said error signal ($\varepsilon_R(n)$).

5. Method according to claim 4, **characterized in that** it includes the operations to calculate the correlations of the third and fifth order of said reference model ($s_R(n)$) and said error signal ($\varepsilon_R(n)$).

6. Method according to claim 4 or claim 5, **characterized in that** it includes, to generate said reference model ($s_R(n)$) at least one of the steps selected in the group consisting of:

- de-rotation of said decision signals (($a_R(n)$) of a carrier recovery phase (21), and
- adaptive filtering (24) with a filter modelling the transmission channel.

7. Method according to claim 6, **characterized in that** said filtering operation (24) is implemented according to a filtering function FIR.

8. System for the transmission of signals between a transmitter (1) and a receiver (2), in which the transmitter (1) includes a stage (9) susceptible to alter the signals transmitted, the system including:

- a detection module (23 a 32) to detect the effect of the alteration action made by said stage (9) of the transmitter (1) on said signals and generate a corresponding control signal (c_i) indicative of the effect of said alteration action,
- a pre-treatment module (4), placed upstream said stage (9), sensitive to said control signal (c_i) and susceptible to submit said signals to a pre-treatment counteracting the alteration action made by said stage (9) of the transmitter (1),

characterized in that:

- said detection module (23 to 32) is placed on the system receiver (2) side, and
- is equipped with a channel (32) to transmit said control signal (c_i) starting from said detection module placed in the receiver (2) towards said pre-treatment module (4).

9. System according to claim 8, **characterized in that** said pre-treatment module is a pre-distorter module (4).

10. System according to claim 8 or claim 9, **characterized in that** said stage (9) is a radio frequency stage of the

transmitter (1) susceptible to distort the transmitted signals.

11. System according to any of the previous claims 8 to 10 for the transmission of digital signals and **characterized in that** it includes, in said receiver (2):

- a decider module (22) to generate decision signals ($a_R(n)$) corresponding to digital signals transmitted,
- a reconstruction module (23, 24) to reconstruct, starting from said decision signals ($a_R(n)$), a reference model ($s_R(n)$) of said signals transmitted ($y_R(n)$),
- a difference module (25) to generate an error signal ($\varepsilon_R(n)$) indicative of the difference between said signals received ($y_R(n)$) and said reference model ($s_R(n)$), and
- a correlation unit (27 to 31) to generate said control signal (c_i) through correlation of said reference model ($s_R(n)$) and said error signal ($\varepsilon_R(n)$).

12. System according to claim 11, **characterized in that** said correlation unit (27 to 31) calculates correlations of the third and fifth order of said reference module ($s_R(n)$) and said error signal ($\varepsilon_R(n)$).

13. System according to claim 11 or claim 12, **characterized in that** said reconstruction module includes at least one of the following:

- a de-rotation element (23) of said decision signals (($a_R(n)$) of a carrier recovery phase (21), and
- an adaptive filter (24) modelling the transmission channel.

14. System according to claim 13, **characterized in that** said filter (24) is a FIR filter.

15. Receiver for system according to any claim 8 through 14.

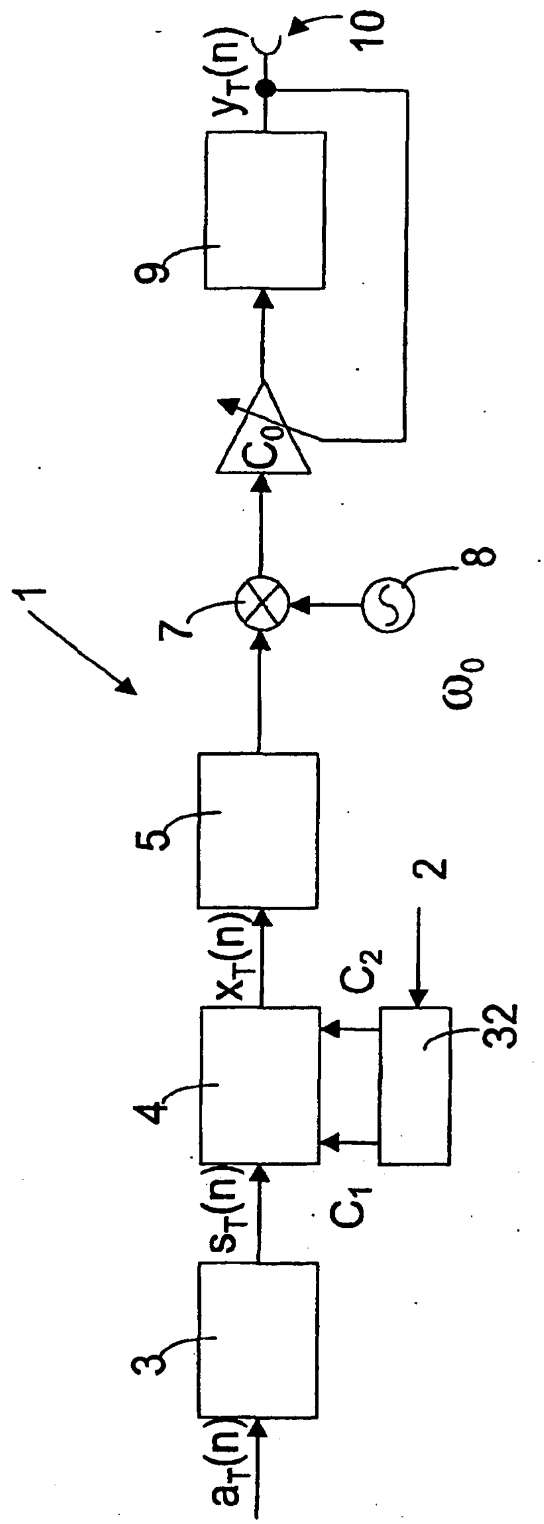
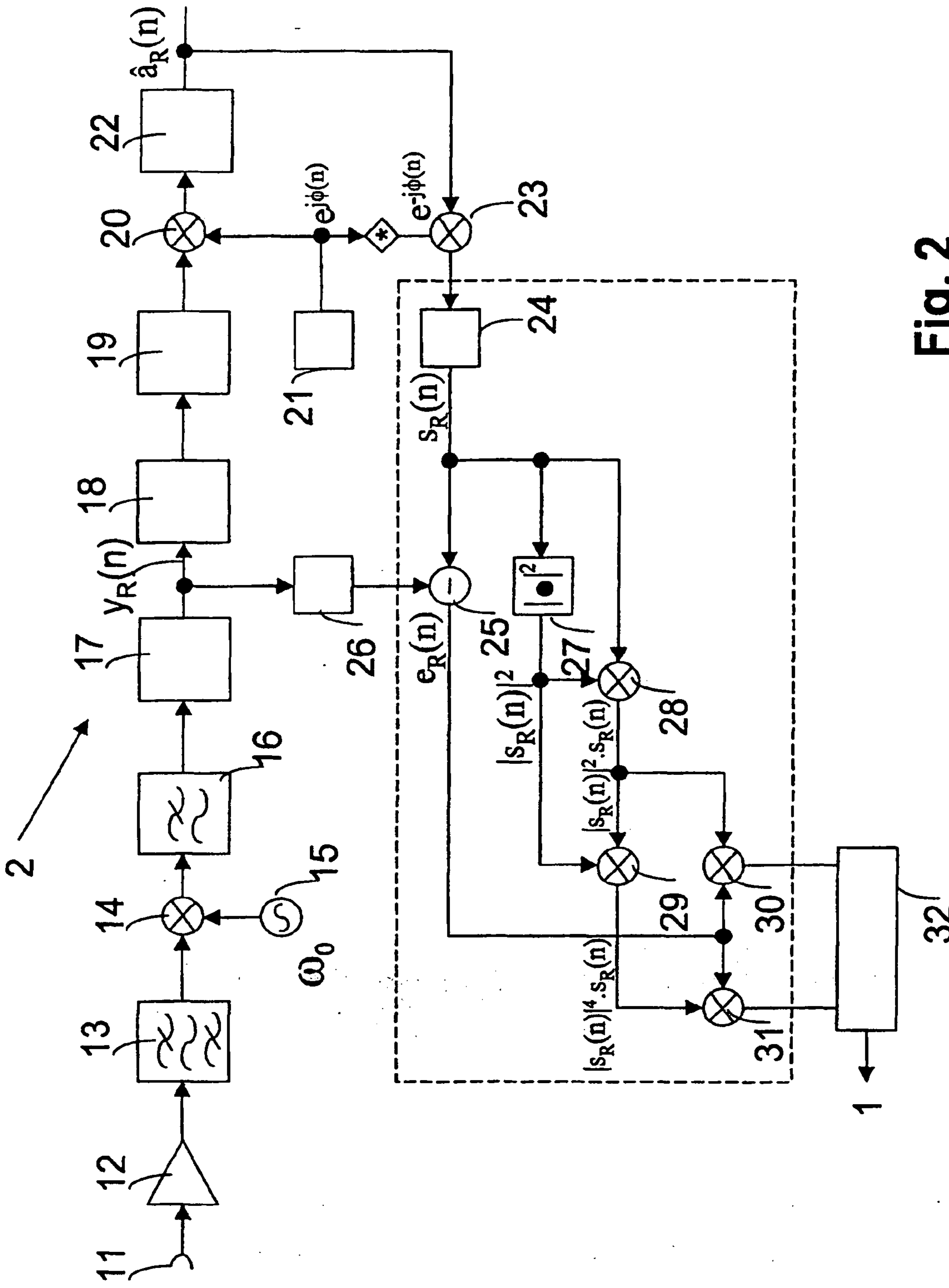


Fig. 1



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|sR(n)|2.sR(n)
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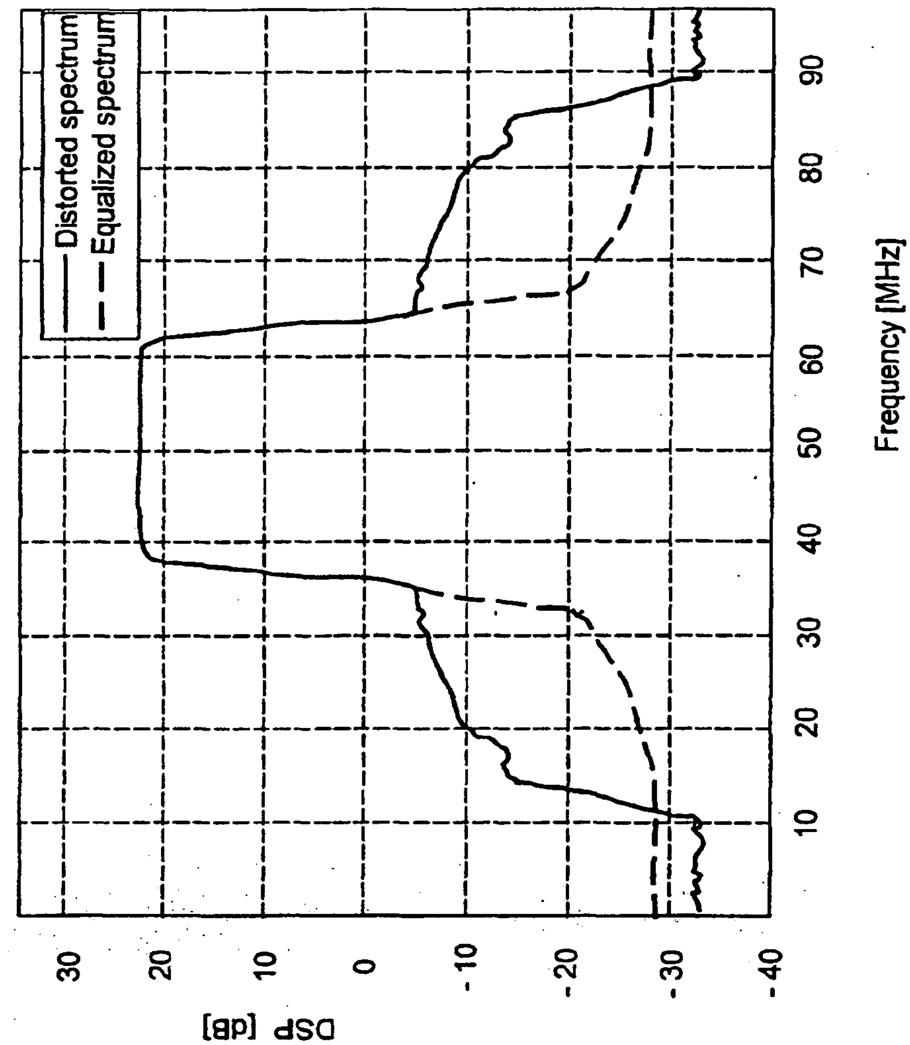
Fig. 2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Equalized spectrum
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DSP [dB]
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10
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EUROPEAN SEARCH REPORT

Application Number
EP 02 01 6408

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X A	WO 98 28888 A (GTE GOVERNMENT SYST) 2 July 1998 (1998-07-02) * abstract * * page 10, line 22 - page 11, line 30 * * figure 1 * ---	1-3, 8-10,15 4-7, 11-14	H03F1/32 H04L27/36
X A	US 5 910 965 A (IERFINO NICK ET AL) 8 June 1999 (1999-06-08) * abstract * * column 1, line 5 - column 3, line 23 * * figure 1 * ---	1-3, 8-10,15 4-7, 11-14	
X A	US 6 173 161 B1 (GROSS JR GEORGE FRANCIS) 9 January 2001 (2001-01-09) * abstract * * column 2, line 7 - column 3, line 26 * * figure 1 * -----	1,2,8,9, 15 3-7, 10-14	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H03F H04L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	22 October 2002	Helms, J

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